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Statistical Comparison of Pooled Nitrogen Washout Data of Various Altitude Decompression Response Groups

Ben F. Edwards, James M. Waligora,
and David J. Horrigan, Jr.

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Decompression Response Groups

Ben F. Edwards
Technology Incorporated
Houston, Texas

James M. Waligora and David J. Horrigan, Jr.
Lyndon B. Johnson Space Center
Houston, Texas

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ABSTRACT

No statistically significant differences were detected in the pooled (averaged) nitrogen washout profiles of subjects belonging to various decompression response groups. The statistical comparisons of the profiles were performed by means of univariate weighted t-test at each 5-minute profile point, and with levels of significance of 5 and 10 percent. The estimated powers of the tests (i.e., probabilities) to detect the observed differences in the pooled profiles were of the order of 8 to 30 percent.

INTRODUCTION

This analysis was done to determine whether decompression response groups could be characterized by the pooled nitrogen (N_2) washout profiles of the group members. Pooling individual washout profiles provided a smooth time-dependent function of means representative of the decompression response group. The four decompression response groups considered consisted of those individuals who (1) exhibit neither bubbles nor pain (group I), (2) exhibit bubbles and no pain (group II), (3) exhibit bubbles and pain (group III), and (4) exhibit bubbles or bubbles and pain (group IV). The nitrogen washout profiles are the time-dependent functions (1) breath N_2 fraction (volume N_2 per volume breath), (2) accumulative exhaled N_2 (liters), and (3) N_2 expiration rate (milliliters per minute). The analytical approach taken is to statistically test, at each 5-minute point, for significant difference between the means of like washout profiles from different groups. A significant difference between any of the group profiles would suggest that individuals belonging to these groups could possibly be differentiated on the basis of their individual washout profiles. On the other hand, if no significant differences are detected, logical conclusions may be (1) that decompression response groups (or individuals) cannot be differentiated by nitrogen washout profile or (2) that the power of the statistical test which is determined by the two group sample sizes and sample variances is not sufficient to detect the differences in group mean profiles.

Decompression response data for this analysis were obtained from the results of three decompression chamber test series (ref. 1). Nitrogen washout profiles (ref. 2) of 27 of the same subjects (some of whom participated in more than one chamber test) were available from the set of washout profiles obtained during the same timeframe. During each test series, the incidence of venous bubbles was detected by a Doppler bubble detector and the occurrence and the level of decompression symptoms were recorded. In all, 173 man-chamber tests were performed with a combined incidence of symptoms of 26 percent and of bubbles, 54 percent. Although some variation existed in the protection protocols, the resulting incidences of symptoms and bubbles were similar.

PROCEDURE

Decompression response and N_2 washout data for the 27 subjects (all male) were segregated into the following 5 groups according to their combined decompression response during the 3 test series.

A. No bubbles or pain (four individuals)

B. Bubbles only (six individuals)

C. Bubbles and pain only (five individuals)

D. Bubbles or bubbles and pain (three individuals)

E. All the preceding (nine individuals)

Groups A, B, and C correspond to response groups I, II, and III, respectively, and the combined groups B, C, and D formed group IV.

Data were processed by copying the individual breath-by-breath N_2 washout data from tape to a directory file and transforming them into time-dependent functions (TRANS6) for the three washout profiles. Individual time-dependent functions for group members are pooled (POOLD6) by addition, and the group average function value and standard deviation σ at each 5-minute point are calculated.

STATISTICAL ANALYSIS

To test the hypothesis that the function means of any two groups are equal, assuming unknown and not necessarily equal variances, a weighted two-tailed t-test is performed (ref. 3). This test is computer programmed (TTIMX) and applied at each of the 5-minute points for each of the three washout functions and for each of the response group pairs, the level of significance being 5 percent, i.e., $\alpha = 0.05$, where α is the probability of rejecting a true hypothesis. Groups II, III, and IV were also paired with group I, with $\alpha = 0.10$.

Power tables (ref. 4) are used to determine the power of the test, $1 - \beta$, where β is the probability of rejecting a true alternate hypothesis. The power of the test, $1 - \beta$, is the probability of accepting a true alternate hypothesis, i.e., detecting an actual difference of specified magnitude.

RESULTS

Similar nitrogen washout profiles of the four decompression response groups are presented in figures 1 to 3 for comparison. Figures 4 to 6 represent the group washout profiles with the largest (but not uniform) differences, e.g., groups I and III, no bubbles and bubbles and pain. For each time point of the three washout functions of each pair of decompression

groups, the statistical hypothesis of equal means was accepted at both the 5- and 10-percent levels of significance as outlined in the procedure.

The power of the t-test, $1 - \beta$, for the various comparisons ranged from 0.08 to 0.30 (8 to 30 percent). Estimates of the sample size N necessary to detect typical profile differences at a 10-percent level of significance and a power of 50 percent ranged from 10 to 68.

DISCUSSION AND CONCLUSIONS

The profiles of figures 1 and 3 show little separation or uniformity of differences. Figure 2 for total expired nitrogen shows uniform separation; however, the profiles are not corrected for residual pulmonary nitrogen, which should account mainly for the large uniform separation. The bend at the 150-minute point is due to a short (150 minute) washout being averaged with the 180-minute data. Figures 4 to 6 illustrate the largest profile differences; however, except for figure 5, these differences are not uniform along the profile. On the basis of the t-test results, there is no significant difference between the pooled nitrogen washout functions of the four decompression response groups. The implication is that the pooled N_2 washout characteristics of the four groups are indistinguishable. On the other hand, the power of the test for equality of means may be too low (because of small sample size and the intrinsic variances) to detect (resolve) differences of the magnitude exhibited here, even though they may actually exist. Larger samples and greater control in the washout procedure may enable a sufficient increase in the power of the test to detect actual differences should they exist.
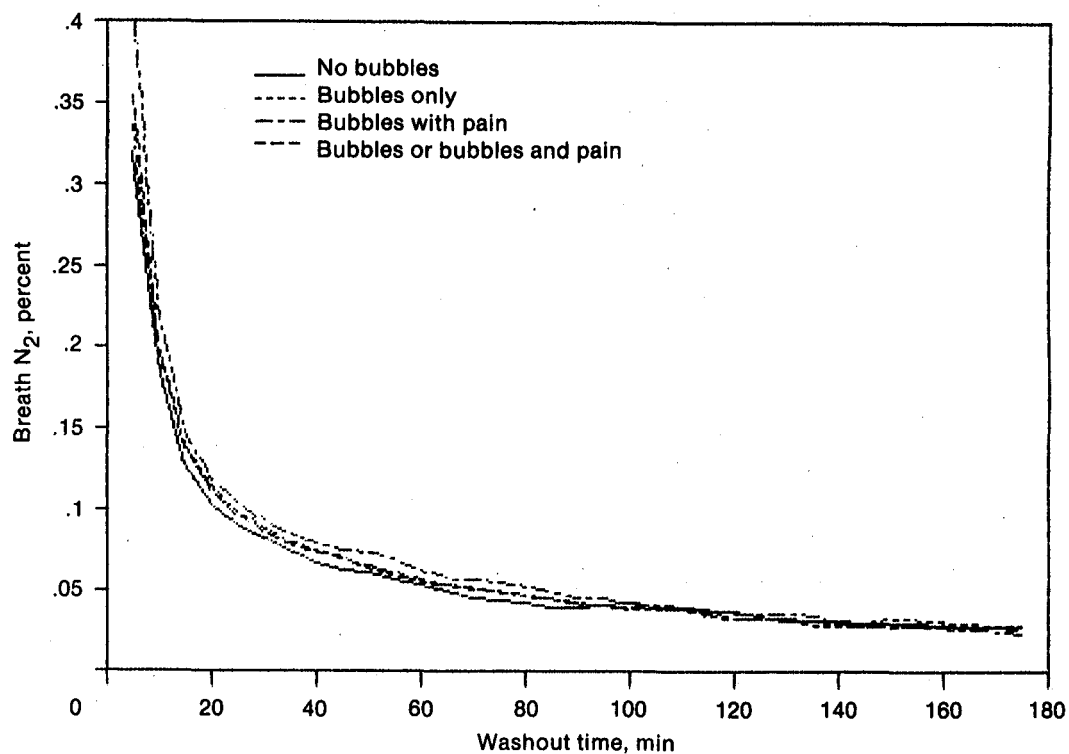
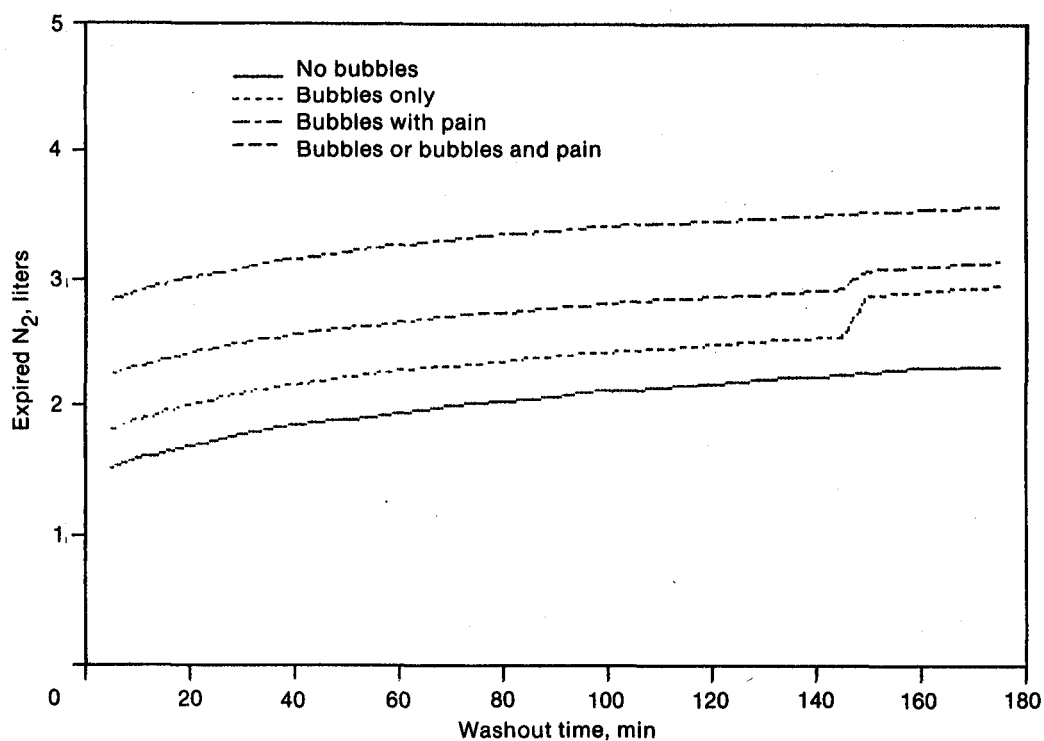Figure 1.- Breath N2 percentage for four decompression groups.

Figure 2.- Total expired N2 for four decompression groups.
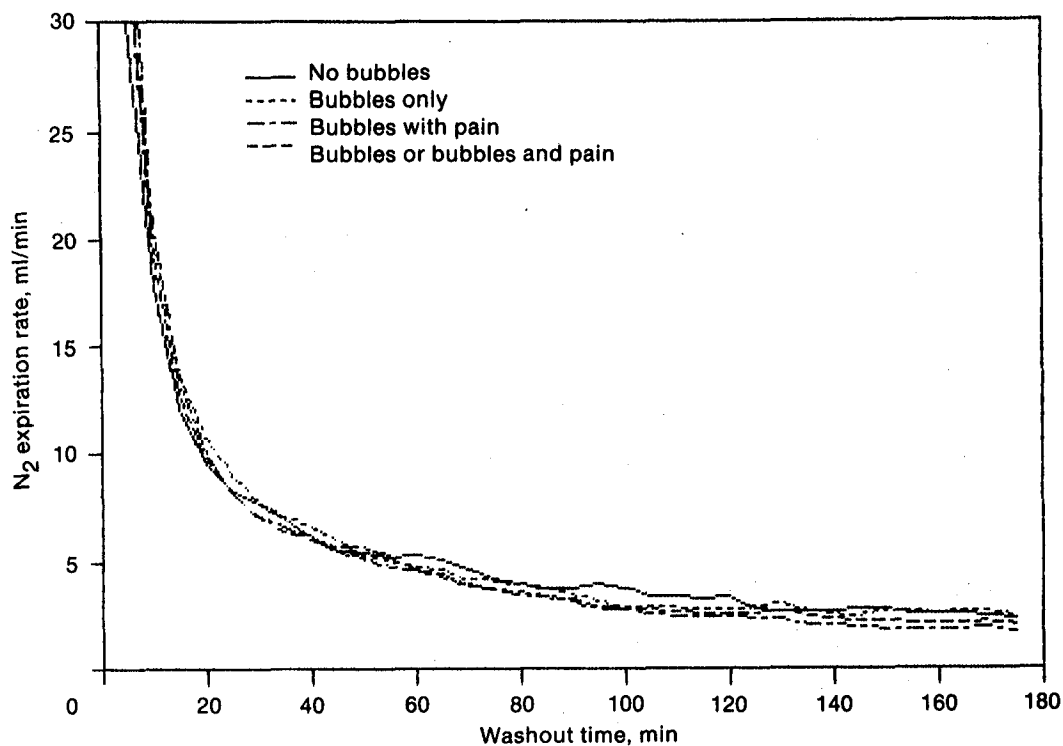
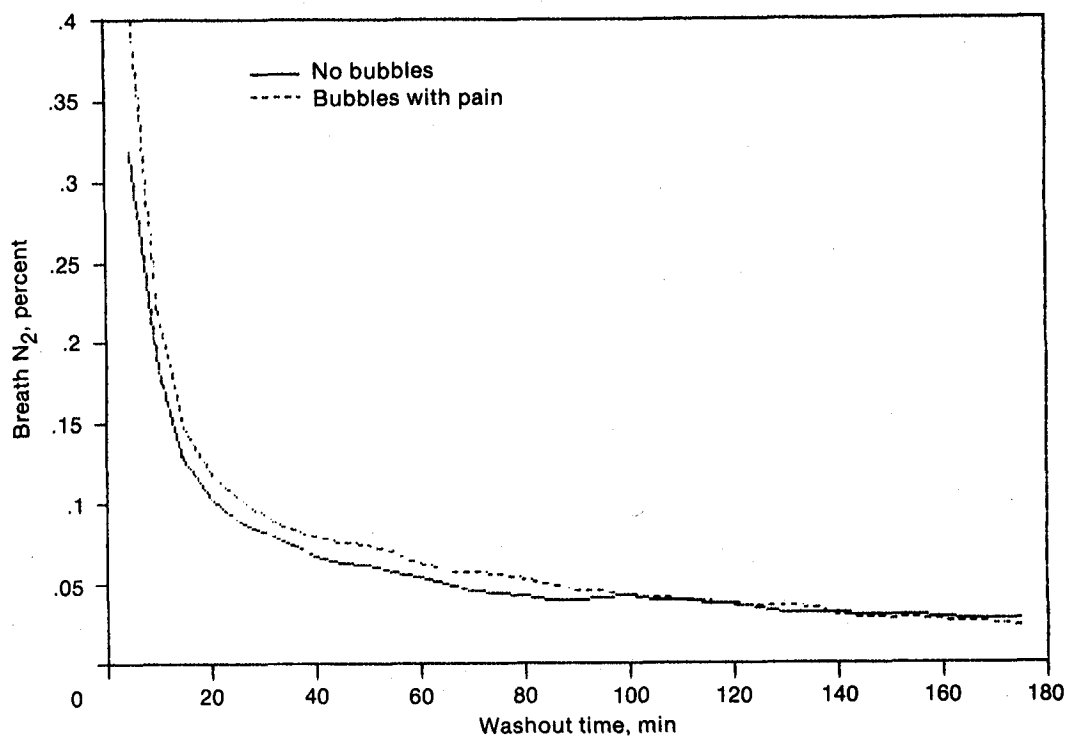Figure 3.- Nitrogen expiration rate for four decompression groups.

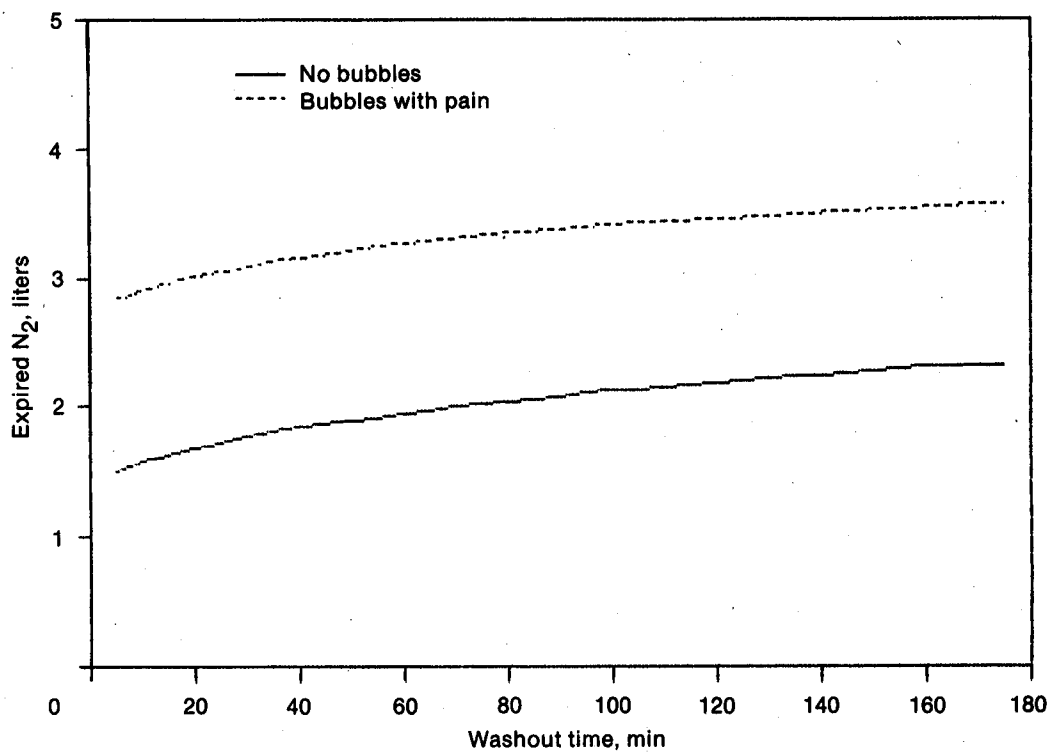Figure 4.- Breath N2 percentage for two decompression groups.

Figure 5.- Total expired N_2 for two decompression groups.
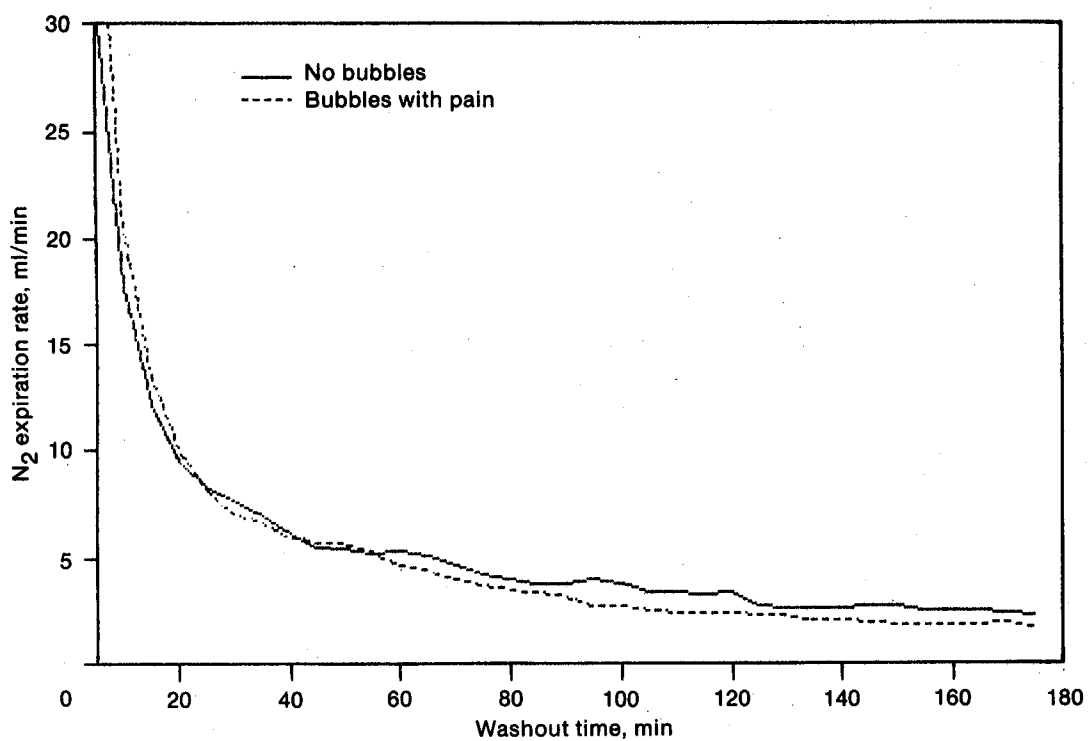

Figure 6.- Nitrogen expiration rate for two decompression groups.

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APPENDIX - EXAMPLE CALCULATIONS

A. T-Test

The procedure for testing the hypothesis of equal means, $Ho:$ $\mu_1 = \mu_2$, a reasonably good approximation procedure when the variances of the two populations are not assumed equal, is as follows (ref. 3).

Compute

$$t' = (\bar{x}_1 - \bar{x}_2)/(w_1 + w_2)^{1/2}$$

and reject

$$|t'| \geq (w_1 t_1 + w_2 t_2)/(w_1 + w_2)$$

where

$$w_1 = S_1^2/N_1 \qquad\qquad w_2 = S_2^2/N_2$$

$$t_1 = t(1-(\alpha/2))(N_1-1) \qquad t_2 = t(1-(\alpha/2))(N_2-1)$$

At the 100-minute point, near maximum separation, the nitrogen (N_2) expiration rate profiles for the "no bubbles" and "bubbles with pain" groups, respectively, provide the following data.

$$\bar{x}_1 = 0.381206 \times 10^{-2}, \; S_1 = 0.144725 \times 10^{-2}, \; N_1 = 4$$

$$\bar{x}_2 = 0.276800 \times 10^{-2}, \; S_2 = 0.110620 \times 10^{-2}, \; N_2 = 5$$

The t-test statistics are computed as

$$w_1 = S_1^2/N_1 = 0.523633 \times 10^{-6}$$

$$w_2 = S_2^2/N_2 = 0.244736 \times 10^{-6}$$

$$t' = (\bar{x}_1 - \bar{x}_2)/(w_1 + w_2)^{1/2} = 1.191$$

$$t_1 = t_{(0.950)(3)} = 2.353, \; \alpha = 0.10$$

$$t_2 = t_{(0.950)(4)} = 2.132, \; \alpha = 0.10$$

$$t_c = (w_1 t_1 + w_2 t_2)/(w_1 + w_2) = 2.286$$

$$t' = 1.191 < 2.286 = t_c$$

Conclusion: Accept Ho: $\mu_1 = \mu_2$.

B. Power of the T-Test

The procedure for determining the power of the t-test is as follows (ref. 4).

Test for equality of variances.

Ho: $\sigma_1^2 = \sigma_2^2$, Ha: $\sigma_1^2 > \sigma_2^2$, $\alpha = 0.05$

$$F = S_1^2/S_2^2 = 1.308$$

$$F = 1.308 < 4.19 = F_{(0.950)(3,4)}$$

Conclusion: Accept Ho: $\sigma_1^2 = \sigma_2^2 = \sigma^2$.

Determine power of the test (two-sided, $\alpha = 0.10$).

$$\hat{\sigma}^2 = \frac{(N_1 - 1)S_1^2 + (N_2 - 1)S_2^2}{N_1 + N_2 - 2} = (0.1264 \times 10^{-2})^2$$

$$d = \frac{\bar{x}_1 - \bar{x}_2}{\hat{\sigma}(1/N_1 + 1/N_2)^{1/2}} = 1.23$$

From reference 4, table A-12b, page 515:

$$1 - \beta = 0.3$$

By induction, select sample size for two-sample single-sided test.

$$\text{Given } 1 - \beta = 0.5, \alpha = 0.05, \text{and } d' = \frac{\bar{x}_1 - \bar{x}_2}{\hat{\sigma}\sqrt{2}} = 0.58$$

Table A-12c, page 516, reference 4: $N_1 = N_2 = 10$

These data were taken from near the point of maximum separation of the group I and III rate profiles yet failed to justify rejecting the hypothesis of equality of group means.

C. Differences in Group I and III Means (III - I) at Various Times

Measurement	Mean at washout time of -		
	10 min	70 min	130 min
N_2 fraction, vol. N_2/vol. breath	0.370×10^{-3}	0.103×10^{-3}	0.349×10^{-4}
Accumulative N_2, liters	0.132×10^{1}	0.132×10^{1}	0.127×10^{1}
N_2 rate, ml/min	0.297×10^{-2}	-0.622×10^{-3}	-0.344×10^{-3}

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15. Supplementary Notes

Ben F. Edwards, Technology Incorporated; James M. Waligora and David J. Horrigan, Jr., Lyndon B. Johnson Space Center

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